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Determining Stress Sensor Requirements for a Health Monitoring System Using Finite Elements

T. C. Miller

Air Force Research Lab

Edwards AFB, CA

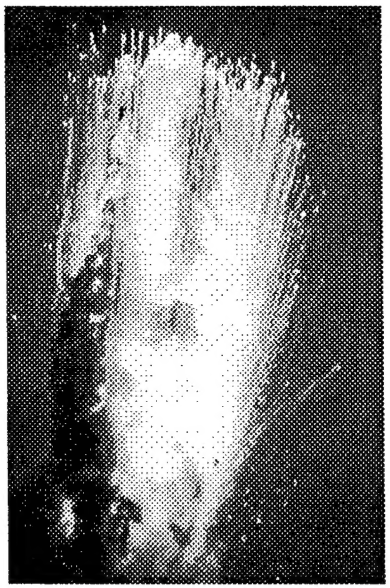
Outline of Presentation

- Introduction
- Computational Modeling
- How FEA Results Are Analyzed
- Summary and Main Points

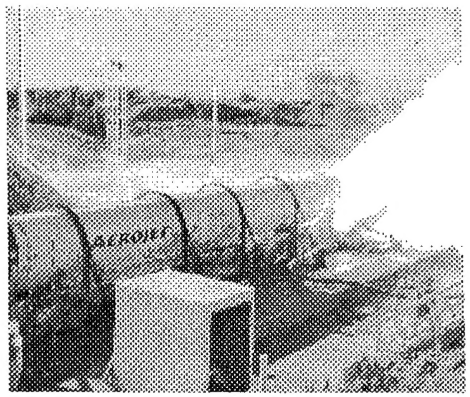
Introduction

Motivation

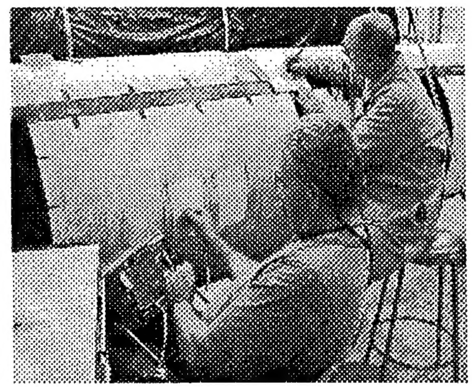
Consequences of Failure



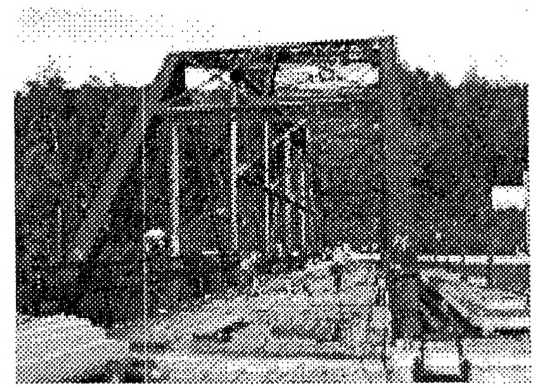
Ways to Ensure Reliability



Live Testing

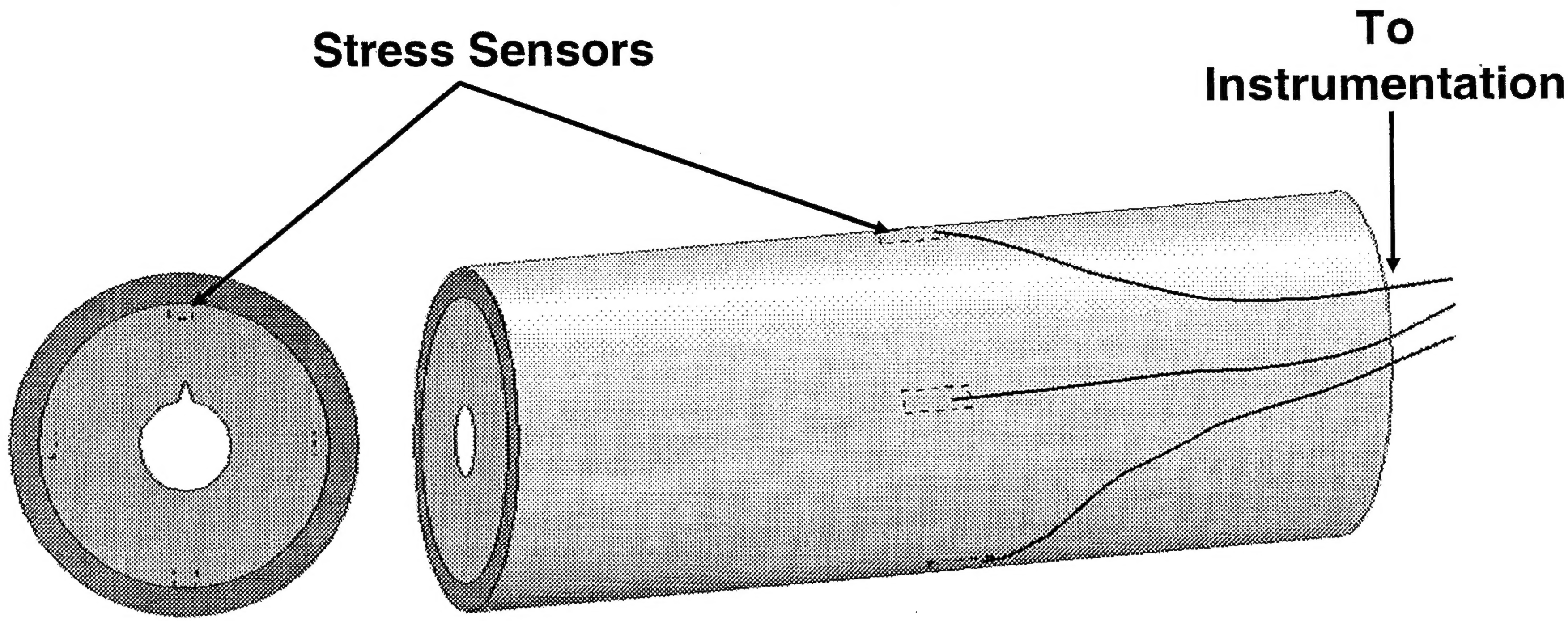


Nondestructive Evaluation



Health Monitoring

Sensors On Inner Case Wall



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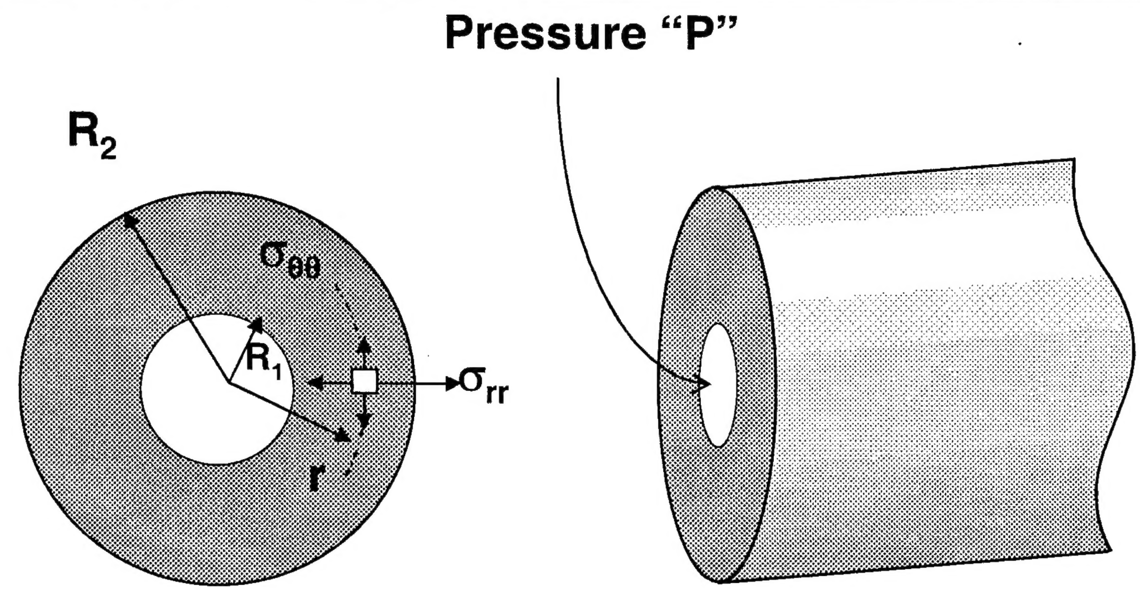
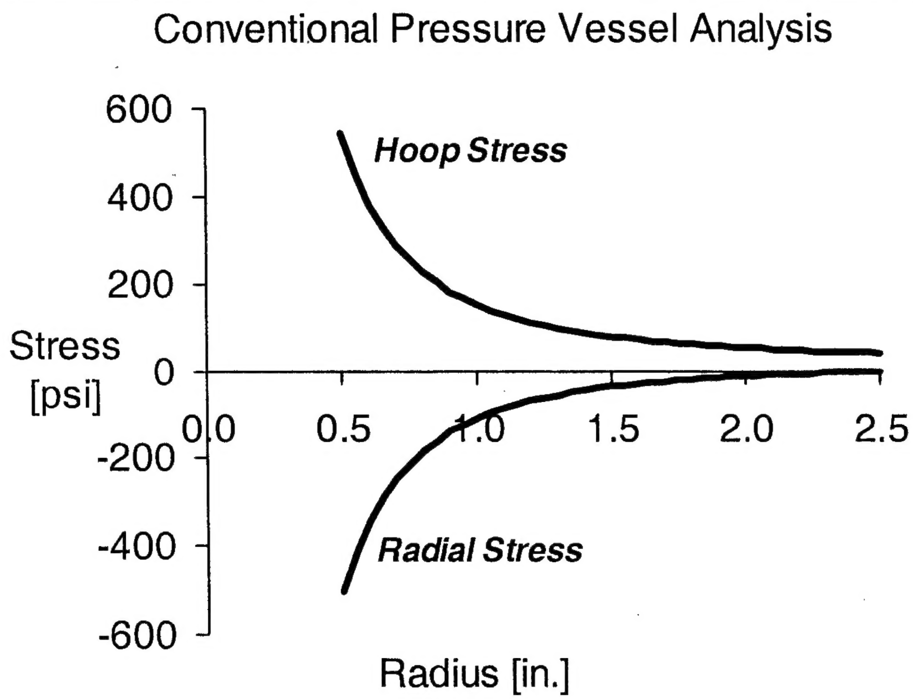
Conventional Analysis For Hoop And Radial Stress

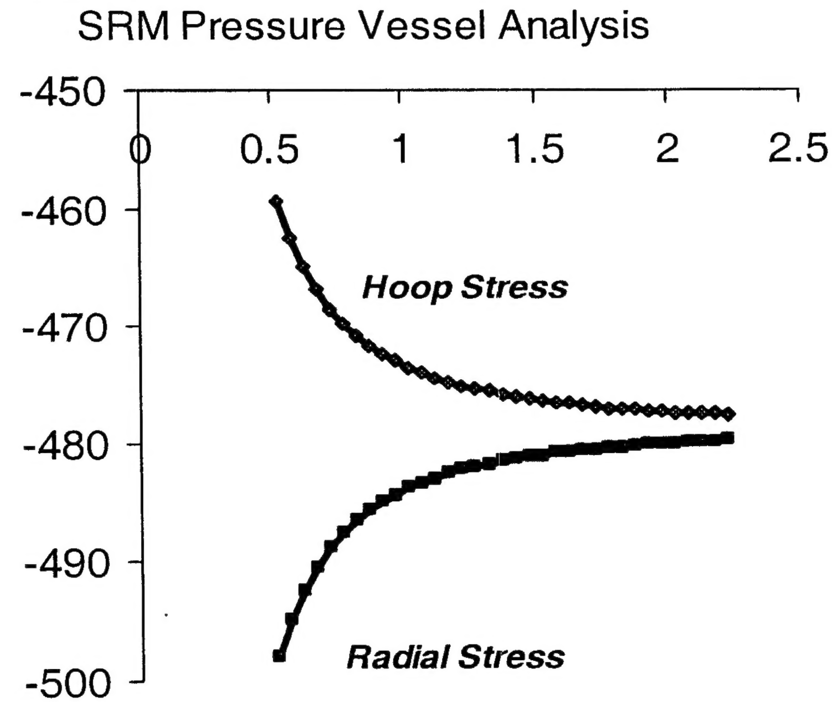


$$\sigma_{\theta\theta} = \frac{pR_1^2(R_2^2 + r^2)}{r^2(R_2^2 - R_1^2)} \quad \sigma_{rr} = \frac{-pR_1^2(R_2^2 - r^2)}{r^2(R_2^2 - R_1^2)}$$

A conventional thick-walled pressure vessel analysis gives tensile hoop stresses but does not apply to solid rocket motors.

Pressure Vessels And Solid Rocket Motors

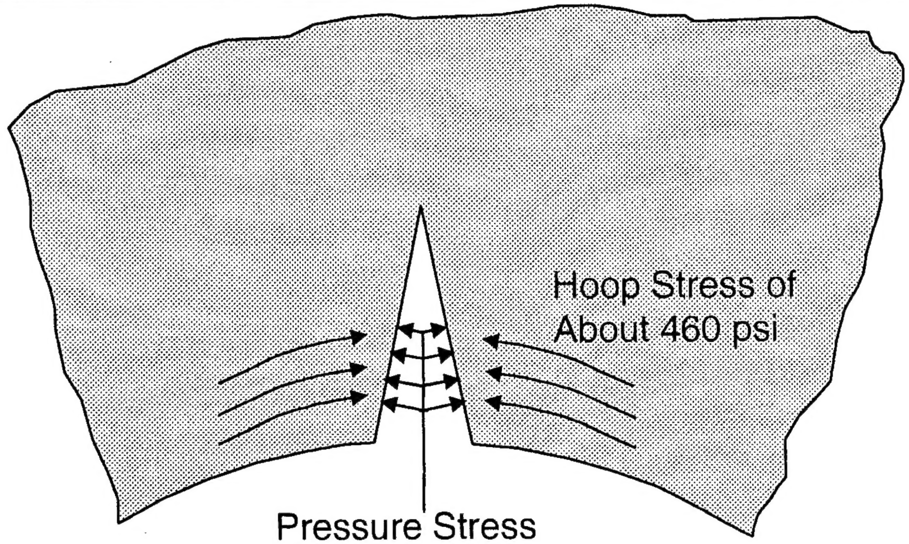




For this motor geometry and loading the stress sensor readings for an uncracked will be close to -500 psi.

Negative hoop stresses would close the crack if it weren't for the pressure loads on the crack faces.

Competing Hoop And Pressure Stresses



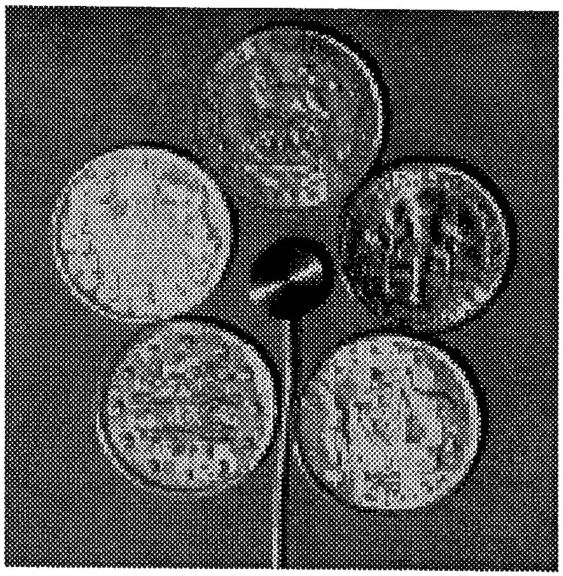
$$K_I = (\sigma_{\theta\theta} + p)\sqrt{\pi a}\, f\left(\frac{a}{t}\right)$$

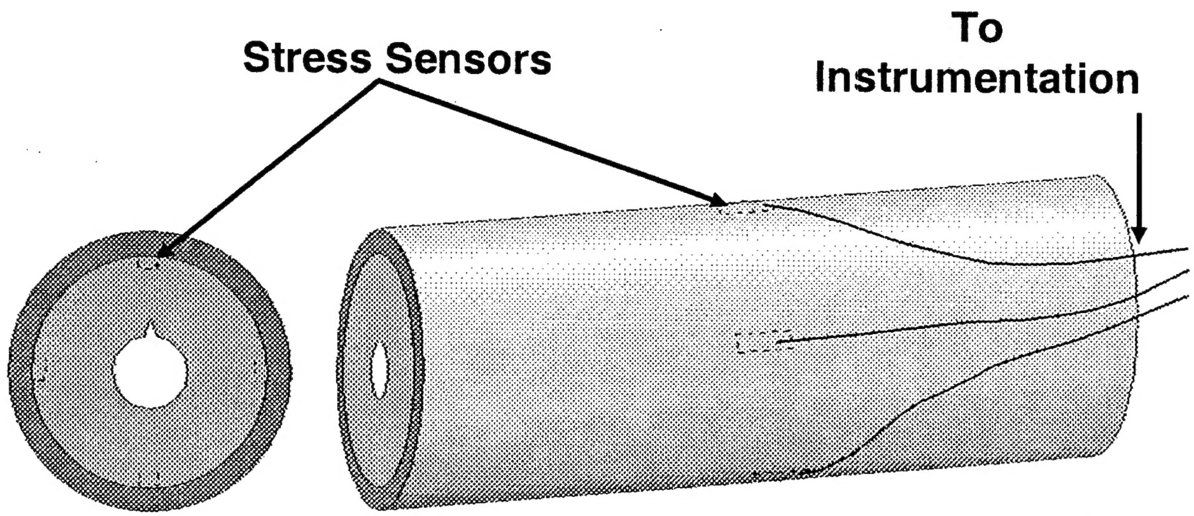
Relatively Weak Driving Force

The combination of negative hoop stress and pressurized crack faces results in substantially weaker "driving force" for fracture.

Sensors On Inner Case Wall

How are the loads, geometry, and characteristics of the sensor system related?





Parameters Affecting HMS Design

- Type and size of load
- Expected crack geometry
- **Requirement for minimum detectable crack size**
- **Number of sensors**
- **Required sensor sensitivity**

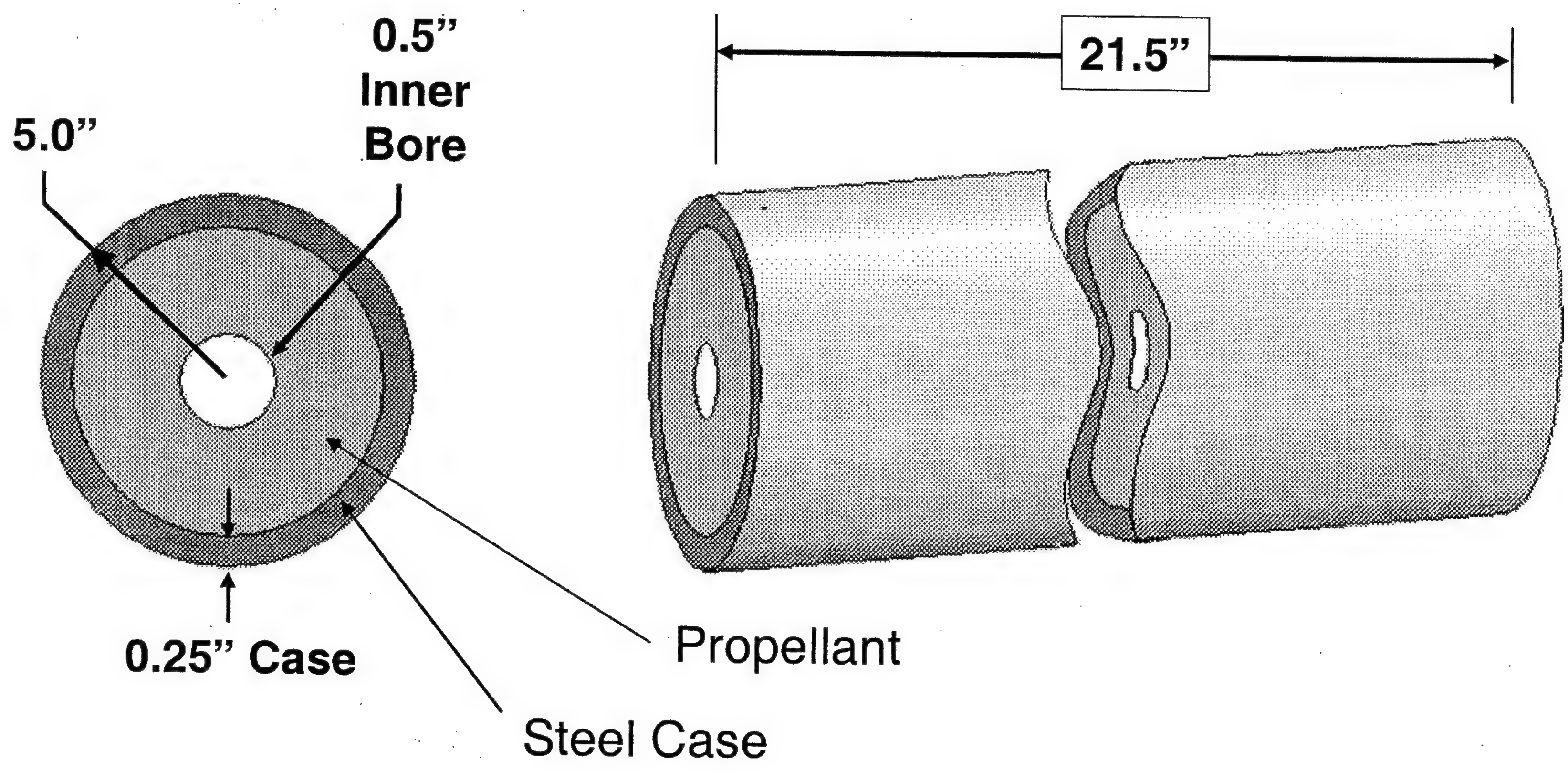
The relationship between some of the system parameters (minimum detectable crack size, required sensor precision, and the number of sensors used) can be found using analysis of FEA data.

Using FEA As A Design Tool

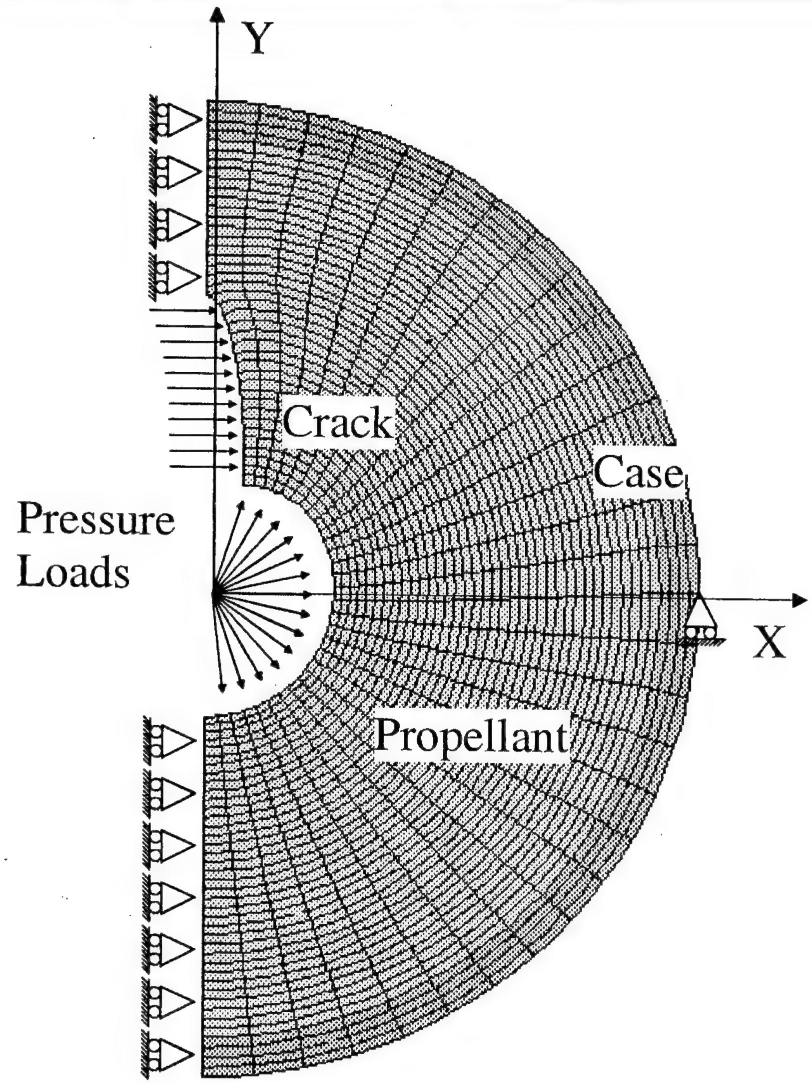
- General method is developed (can be applied to other situations, e.g., thermal loading)
- Specific relationship between variables is found

Computational Modeling

Motor Geometry

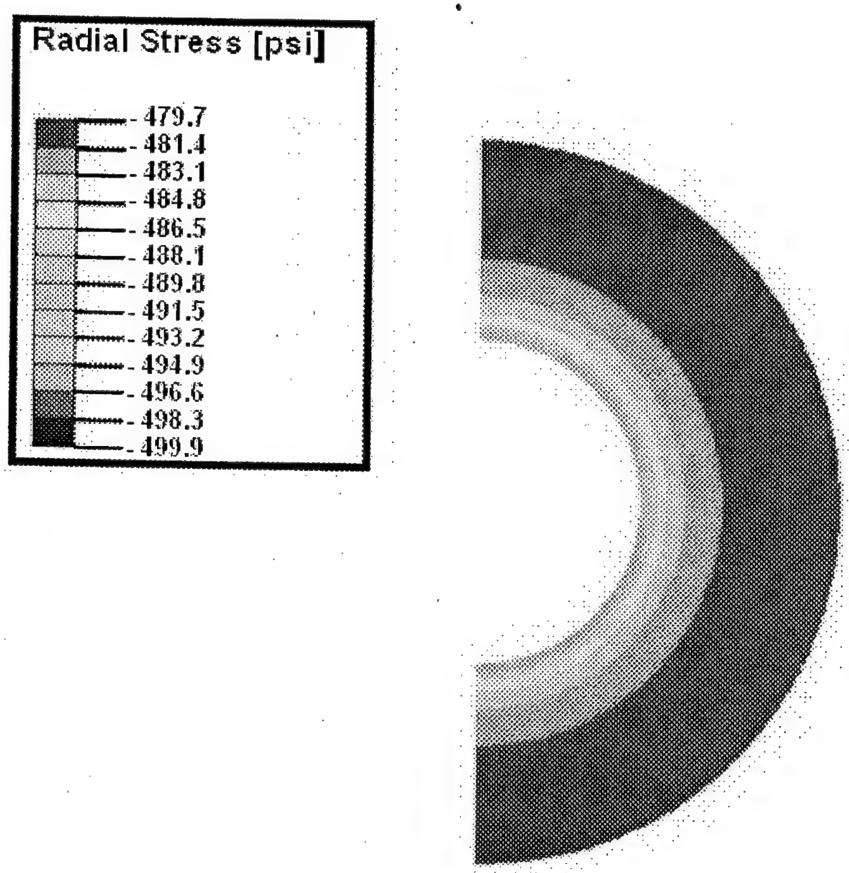


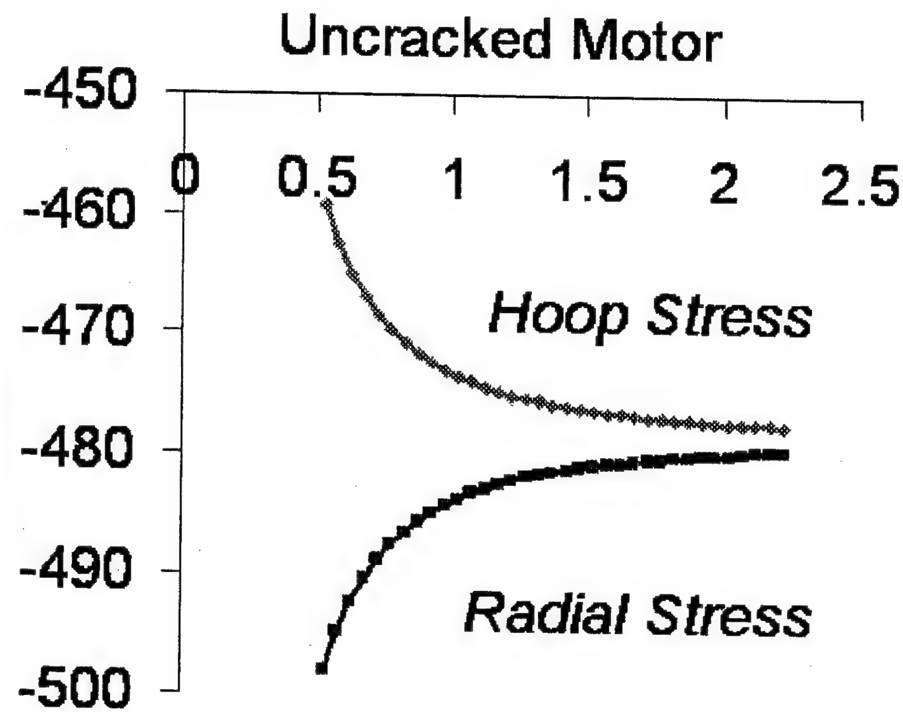
Model Description – Geometry And Loads



FEA Results and How They Are Used

Cracked And Uncracked Solid Rocket Motors





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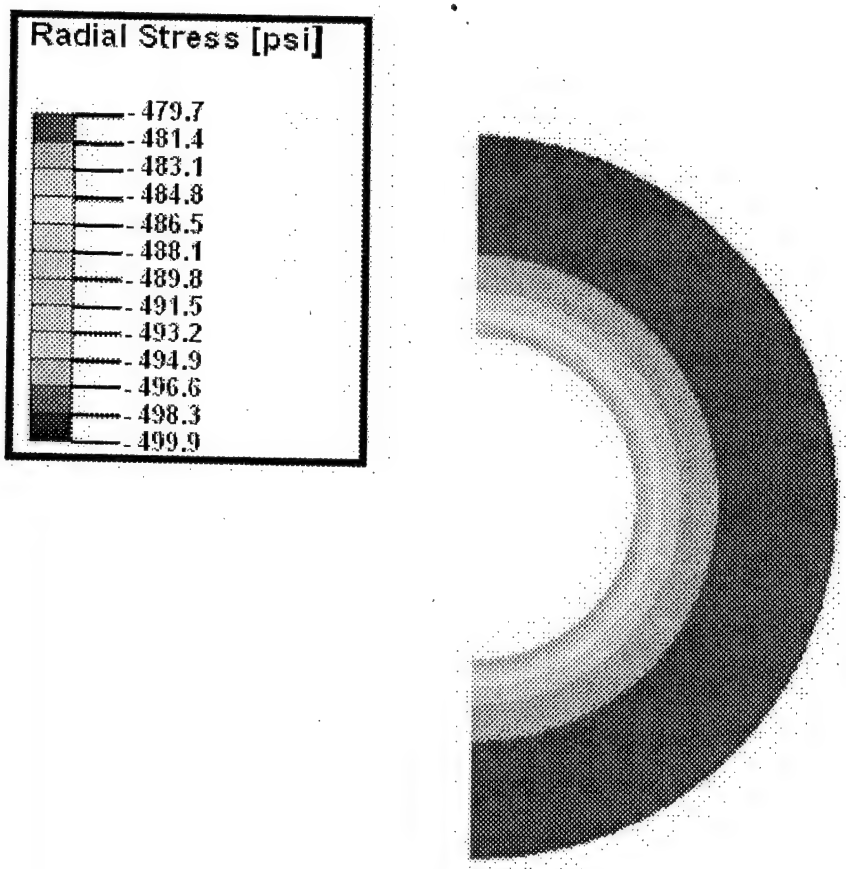

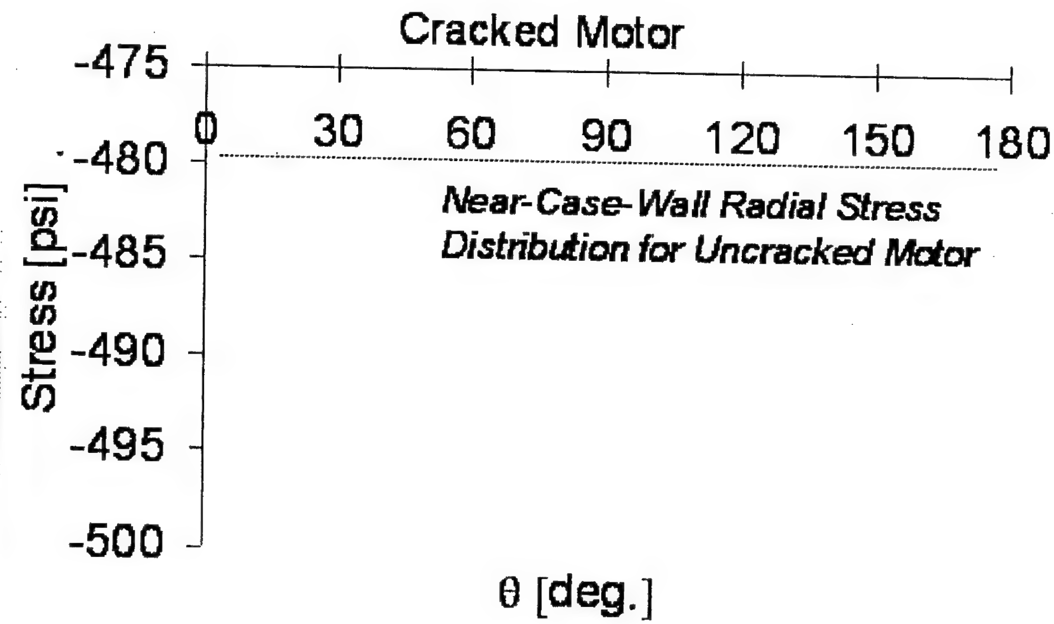

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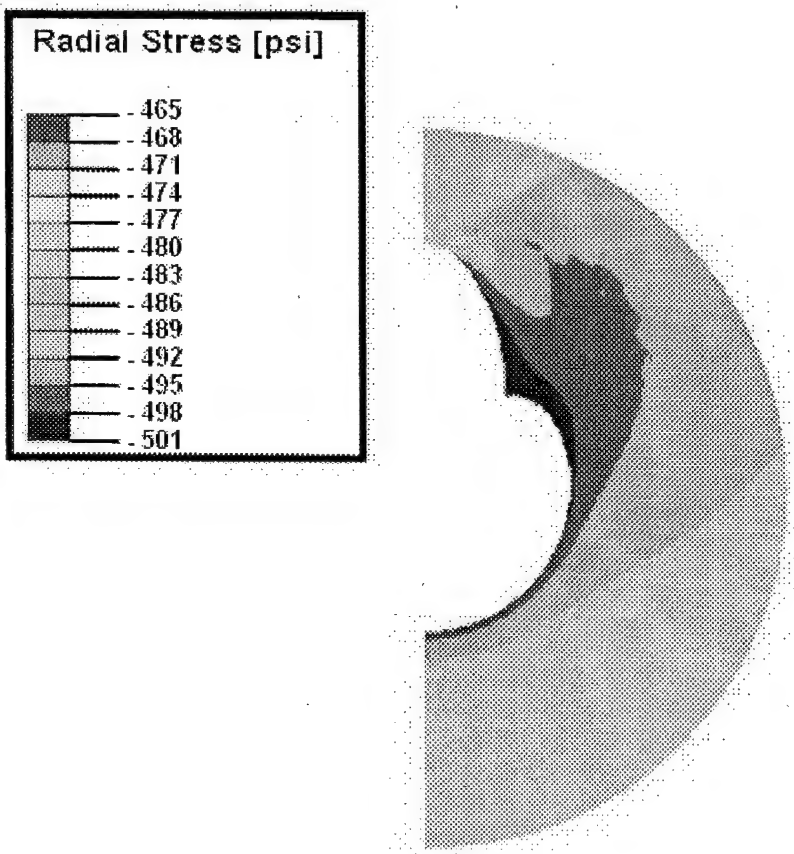
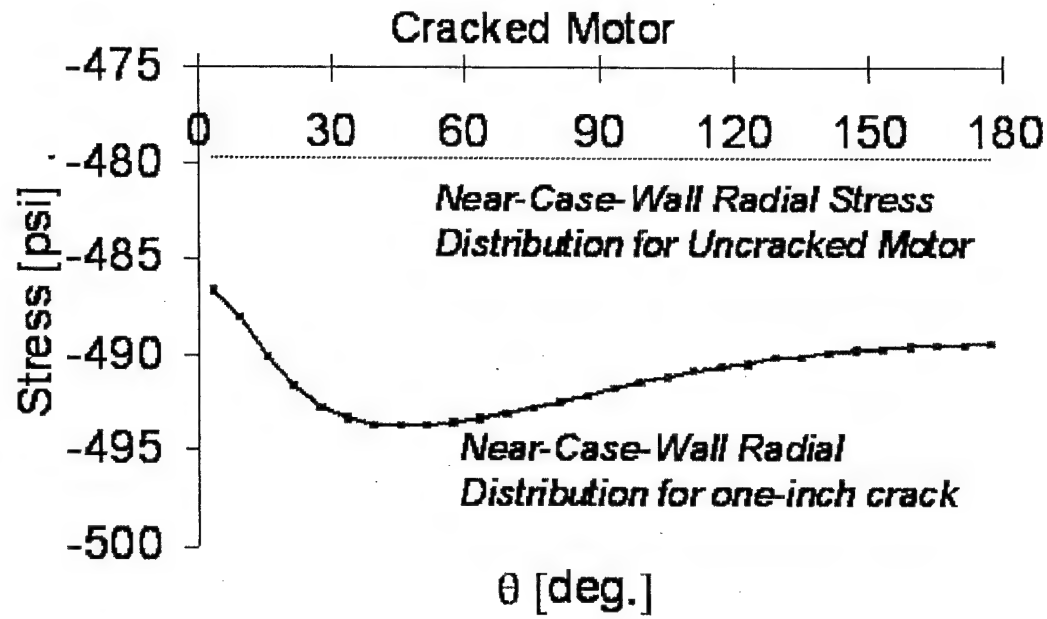
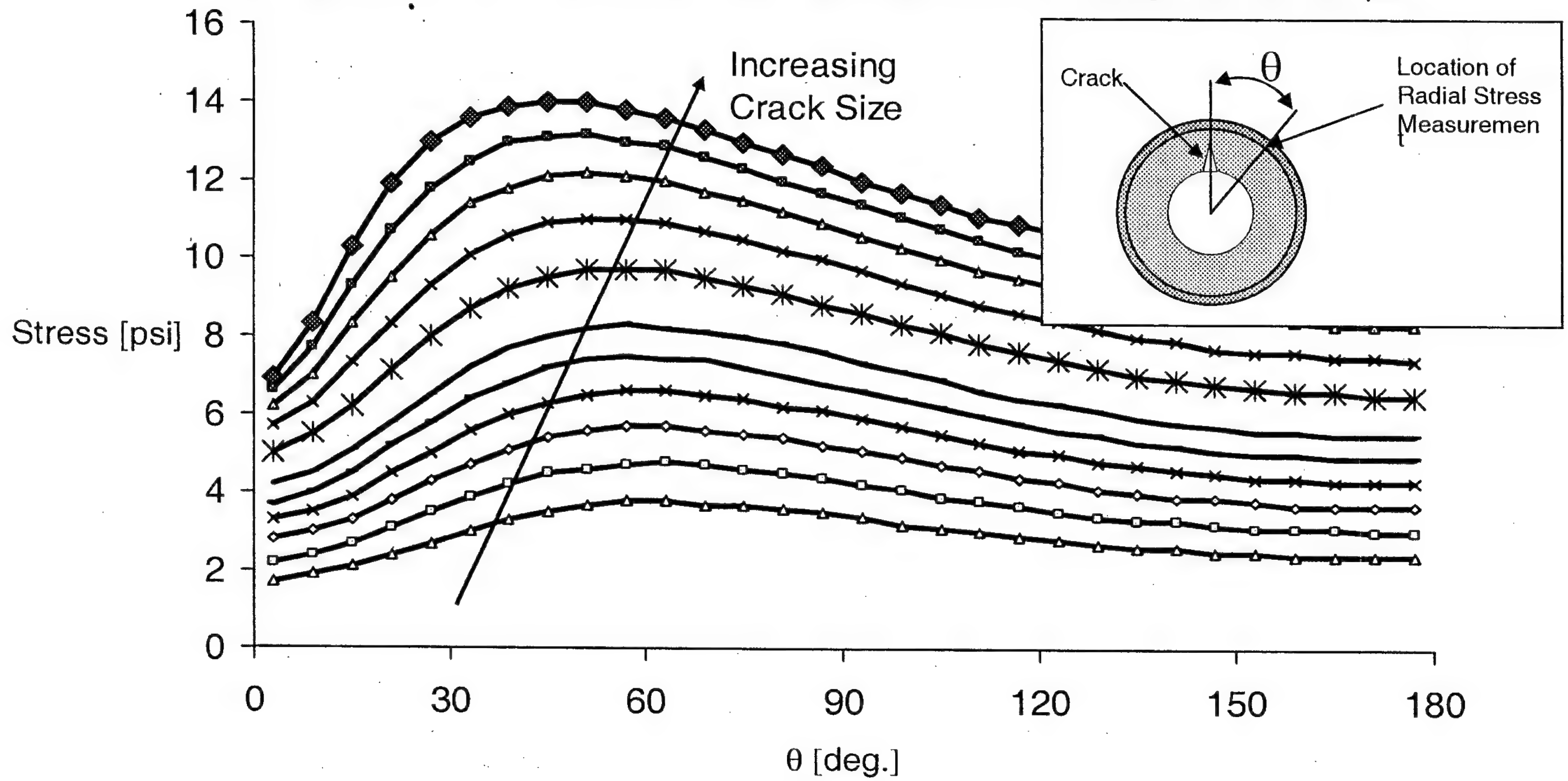




The uncracked motor has "baseline stresses" but the presence of a crack causes deviations that vary with orientation.

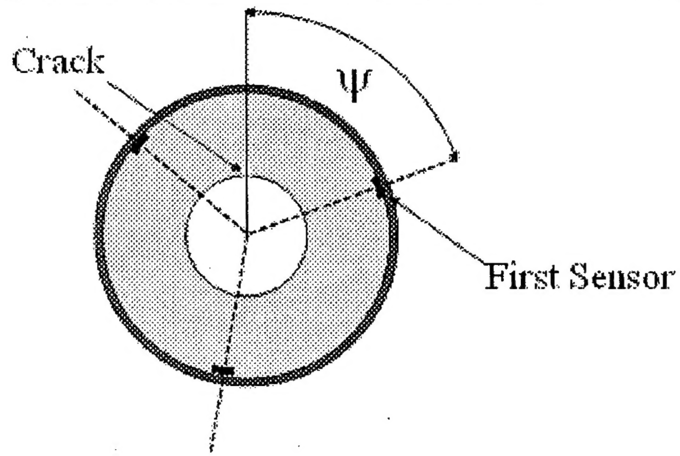
Change In Stresses Near Case Wall Is Felt By Sensors

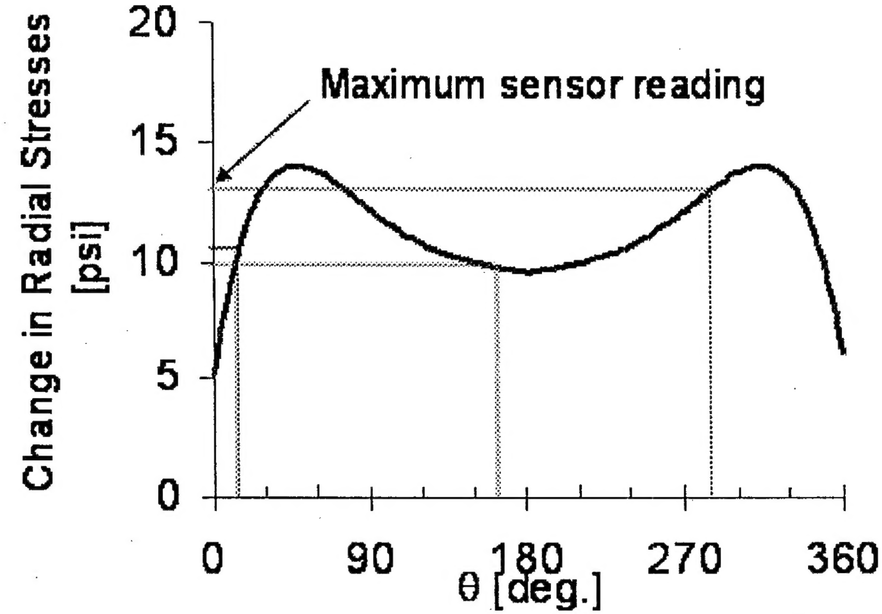
Change in Radial Stress Components Near Case Wall for Analog Motor at 500 psi



The difference between the baseline stresses and the case wall stresses in a cracked motor may or may not be detectable.

How FEA Results Are Analyzed





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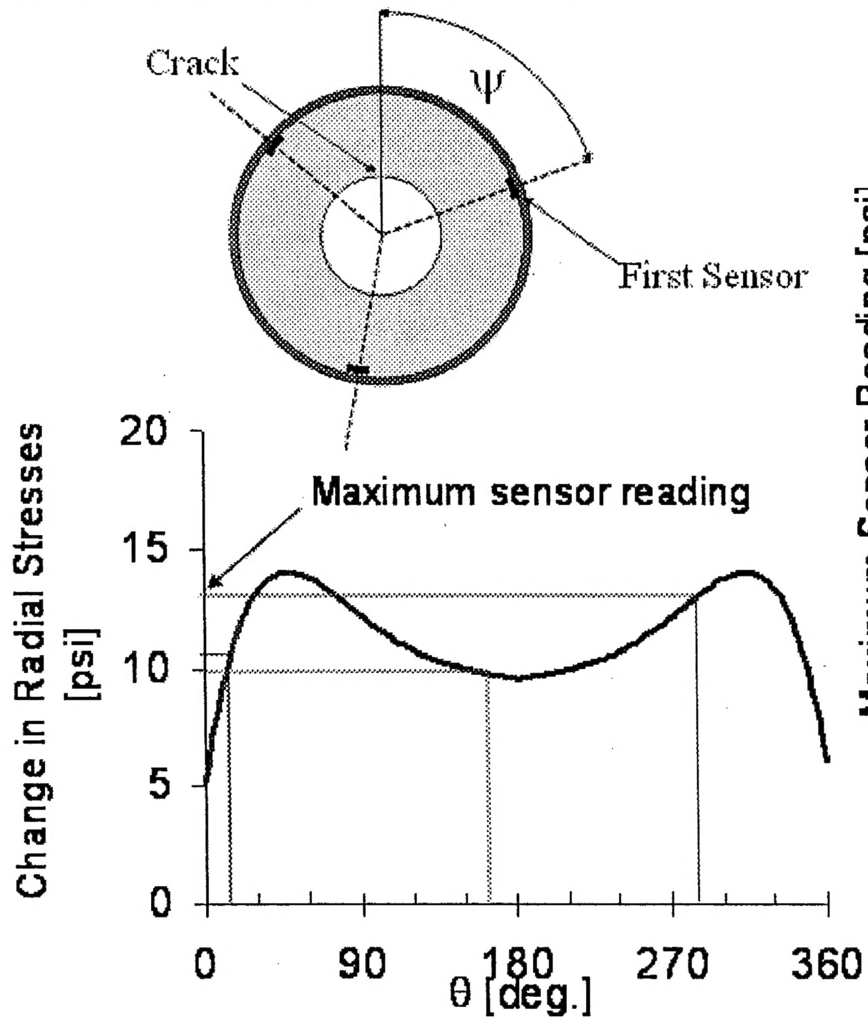
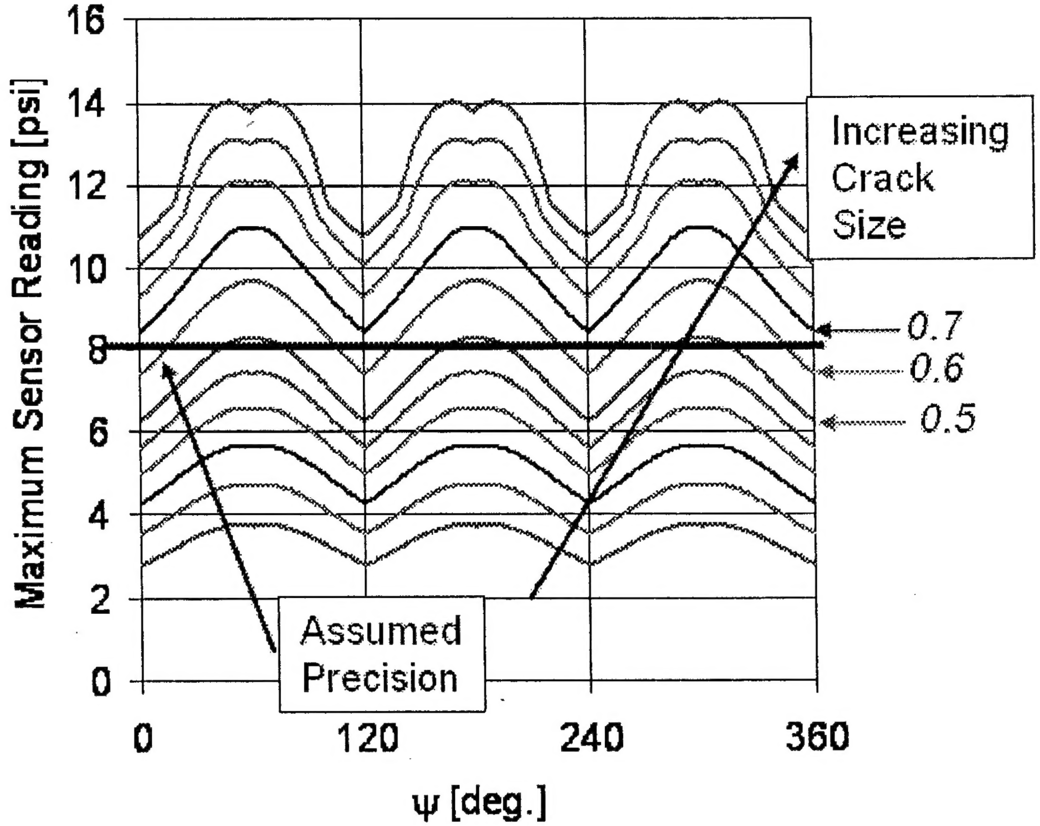
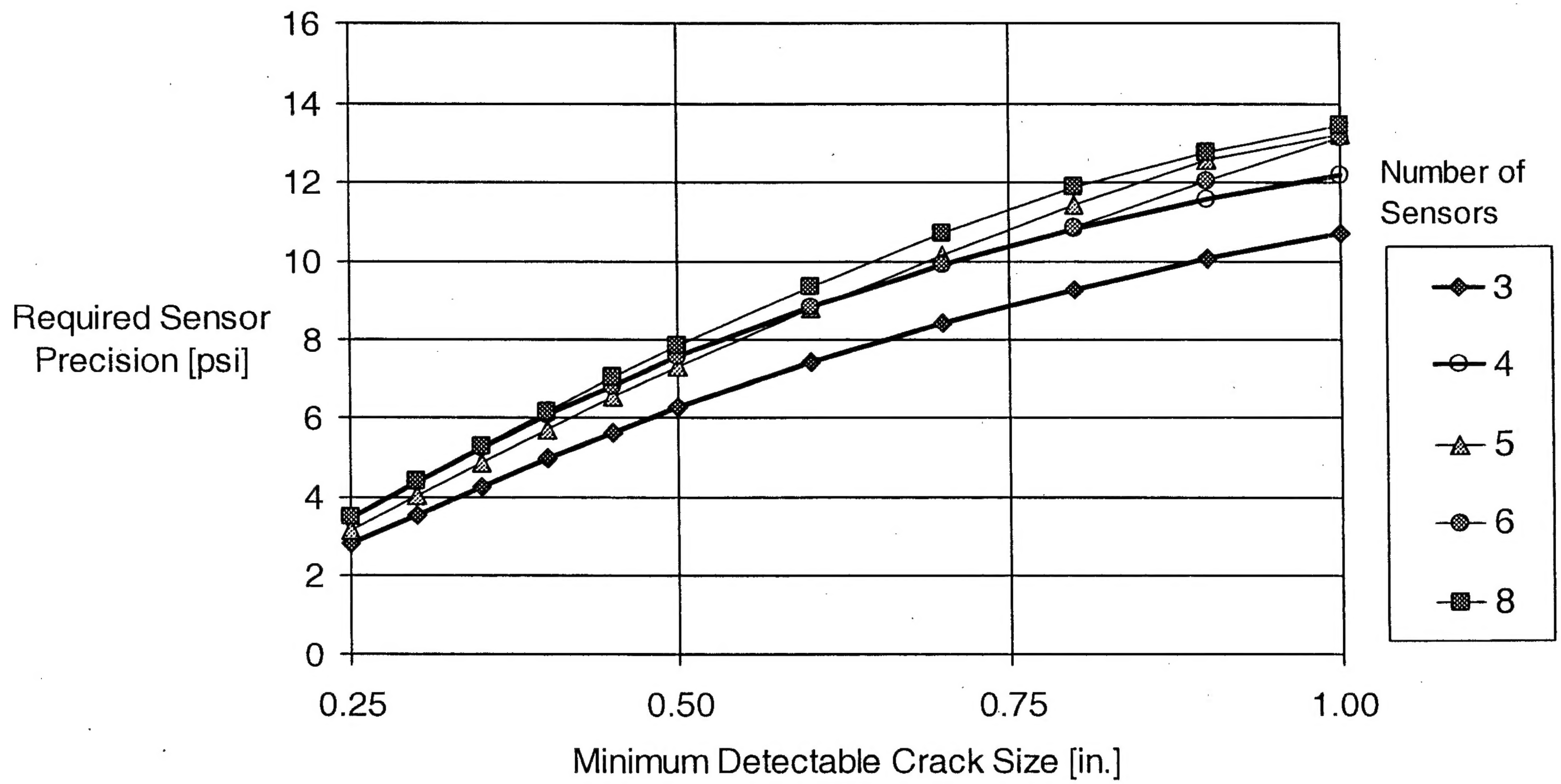




In the worst case scenario, the sensors will be aligned so that the <u>maximum</u> of the three sensor readings will be at a <u>minimum</u>. Detection of the crack may or may not be possible.

Results Relating Number Of Sensors, Sensor Precision, And Minimum Detectable Crack Size



For this motor geometry and loading, the number of sensors recommended is four and the sensor sensitivity required depends on the crack size (quantified by the chart).

Summary and Main Points

A conventional thick-walled pressure vessel analysis gives tensile hoop stresses but does not apply to solid rocket motors.

Negative hoop stresses would close the crack if it weren't for the pressure loads on the crack faces. The combination of negative hoop stress and pressurized crack faces results in substantially weaker "driving force" for fracture.

The relationship between some of the system parameters (minimum detectable crack size, required sensor precision, and the number of sensors used) can be found using analysis of FEA data.

The uncracked motor has "baseline stresses" but the presence of a crack causes deviations that vary with orientation. The difference between the baseline stresses and the case wall stresses in a cracked motor may or may not be detectable.

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